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INTERANNUAL TO DECADAL VARIABILITIES IN THE PACIFIC BASIN IN AN OCEAN GENERAL CIRCULATION MODEL

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1. INTRODUCTION

Unlike the El Nino and Southern Oscillation (ENSO) episodes of the 1980s, anomalous equatorial warming events in the 1990s are more frequent, last for shorter periods, and are less intense [e.g., Liu et al. 1995, Ji et al. 1996]. Unusual conditions in the Pacific basin during the first half of 1990s are characterized by a persistently negative Southern Oscillation index (S01) and positive sea surface temperature (SST) anomalies in the equatorial central Pacific [e.g., Trenberth and Hoar, 1996]. The pattern of SST anomalies forms a horse-shoe pattern, branching out from the equatorial central Pacific to the west coast of North and South America at 20° latitudes [Ji et al. 1996; Kleeman et al., 1996] . The first half decade of the 1990s has experienced three warm episodes: winter 1991/1992, spring 1993, and fall 1994. Most dynamic or statistical forecast models showed useful forecast skill in predicting the anomalous warming during 1982-1992 period, but failed in the 1993 and 1994 episodes, as reviewed by Ji et al. [1996].

The nature of the prolonged anomalous warming in the first half of 1990s is a matter of debate: either it is a new event induced by current factors (e.g., anthropogenically induced greenhouse warming) as suggested by Trenberth and Hoar [1996], or it is part of the decadal-scale variability [Wang 1995; Latif et al., 1997]. Observations available either do not have sufficient quality or are not long enough in duration to clearly resolve the controversy.

In this study, 36 years of surface wind stress and supporting measurements are used to drive an ocean general circulation models. Oceanic responses in terms of temperature, depth, heat content, and current of the upper ocean are examined. The interdecadal and ENSO modes of both the observations and model simulations are compared with the total anomalies, in hope to shed light on the physical causes of the anomalous characteristics of 1990s.

2. MODEL AND DATA

The ocean model used in this study is the Modular Ocean Model version 2 (MOM2) developed at GFDL. Detailed description of the model history can be found in MOM 2 User's Guide and Reference Manual. Vertical subgrid mixing parameterization is Richardson number dependent [Pacanowski and Philander 1981], while the horizontal mixing is nonlinear Smagorinsky [1963] scheme.

The model spans the tropical Pacific from 120°E to 70° W and from 30°S to 30°N. The spatial resolution is 2° longitude by 1/3° latitude between 10°S to 10"N and 1° poleward. There are 28 vertical levels, with 10 m resolution at the top 150 m and relaxed to the bottom at a depth of 5600 m. Sponge boundary condition is applied to the lateral boundaries. Scripps Topography data (1° x 1°) was interpolated to the model grid. A time step of one hour is used in the numerical integration.

The short wave and longwave radiation fluxes apply climatology derived from the monthly International Satellite Cloud Climatology Project (ISCCP) data parameterized using radiative transfer models (SRB, July 1983-June 1991). We used the monthly mean Florida State University (FSU) surface wind stress and Comprehensive Ocean Atmosphere Data Sets (COADS) specific humidity. The FSU wind

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stress covers the period from January 1961 to December 1996 on a 2° latitude by 2° longitude grid between 30”S and 30”N and from 124°E to 70”W. The COADS specific humidity used was from January 1961 to December 1993 on a 2° latitude by 2° longitude grid.

The model was spun up by restoring the surface temperature and salinity to Levitus climatology and later driven by the 36-year (1961-96) wind forcing. The spin up was run for 4 years and the upper ocean reaches quasi-equilibrium seasonal cycle. In the last three years' (199496) model run, specific humidity was replaced by climatology due to lack of data.

In the tropical Pacific during 1992-1996, the simulation of SST and sea level variation compared reasonably well with spacebased observations, in agreement with previous studies [Liu et al., 1995; Liu et al., 1996]. Fourier decomposition analysis was applied to the model simulations to produce interdecadal mode with periods greater than 8 years and ENSO mode with periods from 2 to 7 years.

3. RESULTS

The zonal wind stress anomalies for the 1990-1995 period are characterized by persistent westerly anomalies in the equatorial western and central Pacific and off-equatorial eastern Pacific (Fig. la). Fig. 1b shows that the model SST response is highly correlated with the zonal wind stress. The simulated SST anomalies are similar to the observations, which indicates that the abnormal conditions of observed SST in the 1990s are closely linked to the low-frequency variations in the atmospheric wind forcing. The westerly anomalies result in shallower thermocline depth (as represented by the depth of 20° C isotherm in Fig. 1c) in the equatorial western Pacific and north Pacific around 10° N, whereas the equatorial central to eastern Pacific experiences a deepening of the thermocline in accordance with easterly anomalies. The upper ocean heat content anomalies (figure not shown) are very similar to the thermocline anomalies. The mixed layer depth (figure not shown) features negative anomalies to the west and positive anomalies to the east of the basin, consistent with the thermocline variations on the interdecadal time scale. The close resemblance between the interannual anomalies and the interdecadal modes shown in Fig. 2 implies that anomalies in the 1990s for both the atmospheric forcing and upper ocean responses are dominated by the interdecadal variability.

Averaged anomalies between 90-95

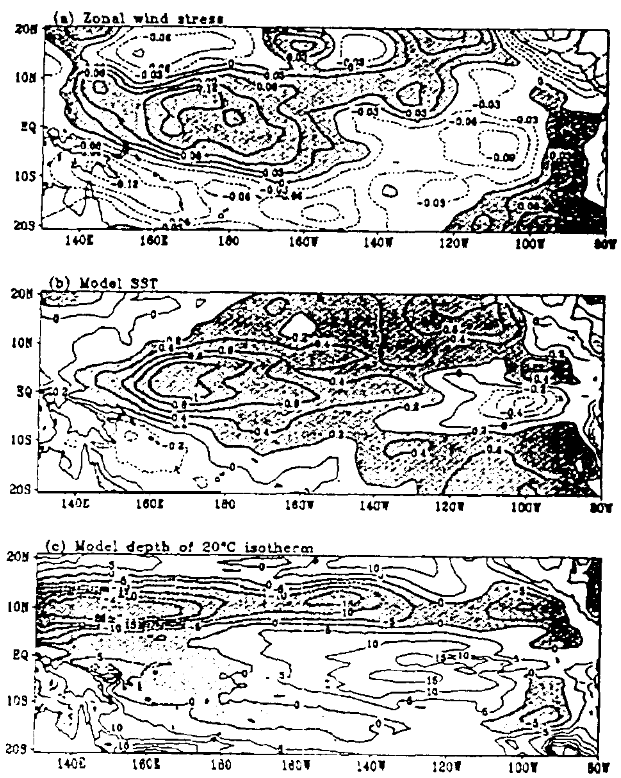

Figure 1: Interannual anomaly of (a) zonal wind stress, (b) sea surface temperature and, (c) depth of 20°C isotherm derived from model simulation and averaged for six years (1990-199.5). The anomalies are deviations from the 36-year (1961-1996) averaged annual cycles.

Fig. 3 depicts time-longitude cross sections of the interdecadal mode of zonal wind stress, model SST, and 20” C isotherm. It is shown that the interdecadal component of zonal wind stress has westerly anomalies in the western and central Pacific during the 1990s, which reinforces the ENSO component shown in Fig. 4. Accordingly, the SST response during the same period is at the warm phase of the interdecadal mode (Fig. 3). A shift from cold to warm phase of the interdecadal mode around 1977 is obvious in Fig. 3; the shift in SST is consistent with the shift from easterly to westerly zonal stress anomalies. The thermocline deepens to the east of the warm SST on the interdecadal time scale. During the short-lived warming events in 1993 and 1994, amplitudes of the interdecadal variation are comparable or even larger than the ENSO mode. Especially during the 93 basin warming, the interdecadal mode plays a dominant part in the total anomalies both for the wind forcing and upper ocean responses such as SST and thermocline depth.

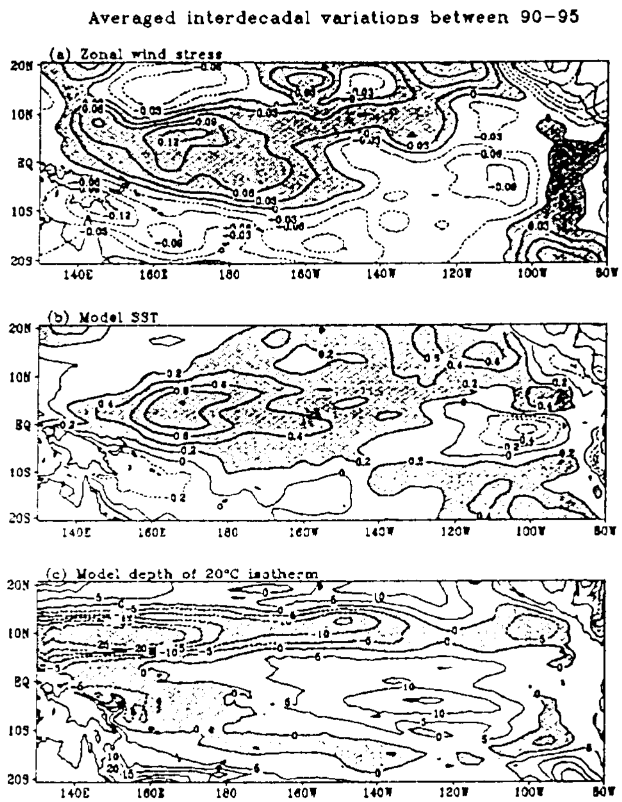

Figure 2: Same as Fig. 1, except for interdecadal modes instead of interannual anomalies. The interdecadal mode is defined as the variation with period longer than 8 years and was derived from the 36-year simulation through Fourier decomposition.

The thermocline evolution differs notably between the traditional moderate-to-strong ENSO events such as those in the 19S0s and 1991/92 and the latest two warming events. In a traditional ENSO, the western Pacific warm pool displays below-normal sea level pressure and significant deepening of the thermocline at least one year prior to the eastern

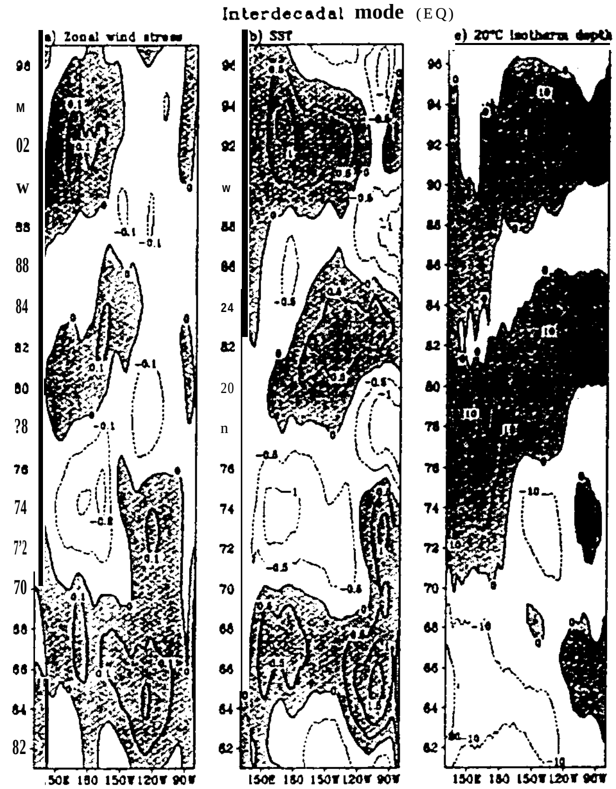

Figure 3: Longitudinal and temporal variations of decadal modes of (a) zonal wind stress, (b) sea surface temperature, and (c) depth of 20°C isotherm along the equator.

Pacific warming, resulting from the strong-than-normal Pacific trade wind. The recent two warm events, however, developed against the anomalously very shallow western Pacific thermocline. This is most evident in the total anomalies of 20° C isotherm depth (not shown), and also evident in both the interdecadal and ENSO modes (Fig. 3c and Fig. 4c).

In the eastern Pacific, the interdecadal mode (Fig. .5a) has large amplitude slightly off the equator while the ENSO mode (Fig. 5b) has the largest amplitude within the equatorial wave guide. The model-simulated SST anomalies (Fig. 5c) have large amplitudes during the 1982/1983, 1986/1987, and 1991/1992 ENSOS near the equator, whereas the

1993 and 1994 episodes exhibit considerable warm SST off the equatorial region. In the core region of the traditional ENSO in the equatorial Pacific, there are negative SST anomalies. The close resemblance between Fig. .5a and 5c for 1993 and 1994 implies that the interdecadal variation contributes significantly to the total SST anomalies, particularly in the off-equatorial regions.

duced by the much weaker interdecadal variations in the model response (figure not shown), which suggests that the interdecadal mode of the upper ocean response is closely associated with the atmospheric forcing on the same time scale. Compared to the control run, the latest two warm events are especially suppressed, indicating that the interdecadal variation plays an important role in the warming.

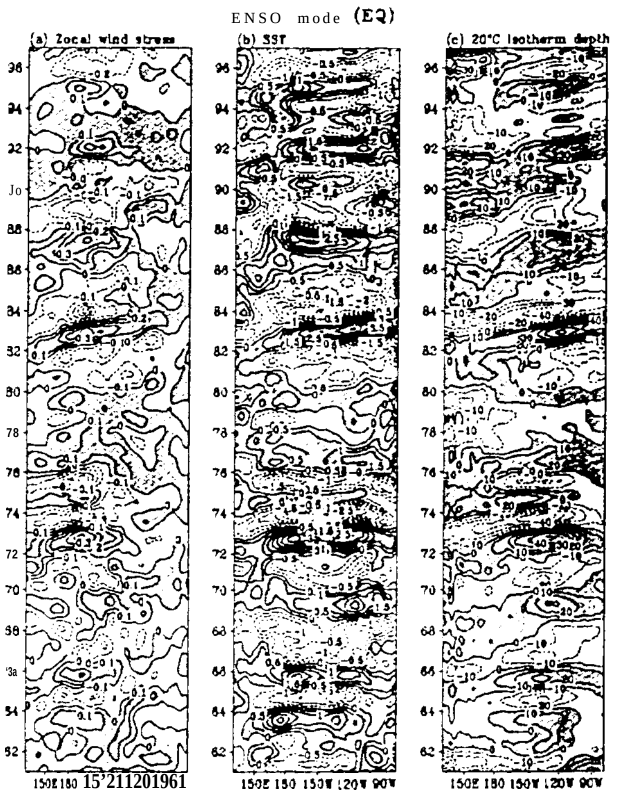

Figure 4: Same as Fig. 3, except for ENSO mode instead of decadal mode. The ENSO mode is defined as the variation with period between 2 to 7 years and was derived with the same method as the interdecadal mode,

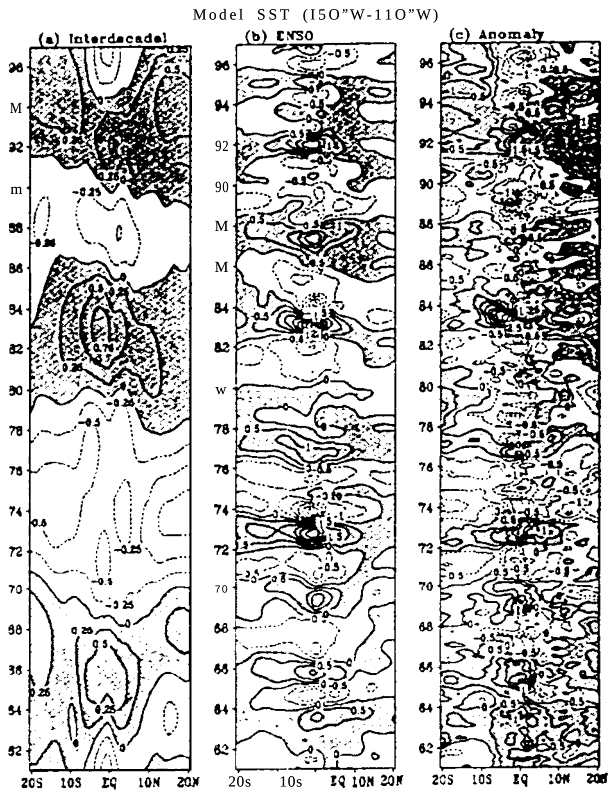

Figure ,5: Latitudinal-temporal variation for (a) decadal mode, (b) ENSO mode, and (c) total variance of sea surface temperature of a meridional band betw 150° W and 110° W.

In order to further understand the physical mechanisms of the anomalous characteristics in the 1990s, experiment was conducted with the interdecadal mode removed from the wind and specific humidity (i.e., from the wind and heat forcing), The averaged SST response for 1990 -199.5 shows much reduced warming in the equatorial central Pacific and off-equatorial eastern Pacific (Fig. 6). This is in-

The interdecadal variation accounts for a significant part of the characteristics displayed in the latest two short-lived warming such as large off-equatorial eastern Pacific warming and little or negative warming in the equatorial eastern Pacific which is the key region of warming for traditional ENSO.

4. CONCLUSION

The 1991/92 anomalous warming episode is found to be similar to the ENSO events in 1980s, whereas the latter two weak and short-lived episodes differ significantly in the sense that latter two were developed from very shallow western Pacific thermocline. A significant portion of the 1993 and 1994 warming episodes were explained by the interdecadal variations. This may be one of the factors why most of the forecast models failed to predict adequately the latest two episodes. The resemblance of the geographic and temporal distributions of the total anomalies and the interdecadal mode averaged over the first half of 1990s in observed wind stress, simulated SST and thermocline depth implies that the anomalies in the 1990s are likely to be dominated by the interdecadal mode. The low-frequency variations from interannual to interdecadal time scales of the upper ocean responses are closely associated with atmospheric dynamic and thermodynamic forcing.

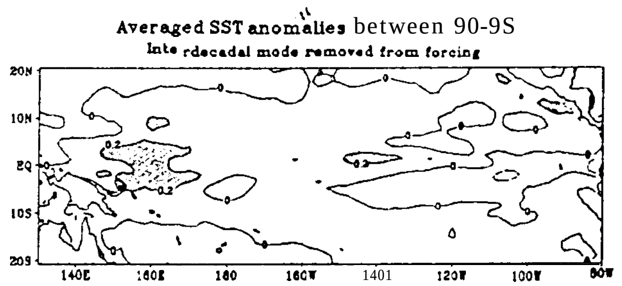

Figure 6: Average (1990-1995) of model-simulated sea surface temperature anomalies when forced by zonal wind stress and atmospheric humidity with decadal mode removed.

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REFERENCES:

Ji, M, A. Leetmaa, and V.E. Kousky, 1996: Coupled model predictions of ENSO during the 1980s and the 1990s at the National Centers for Environmental Prediction. *J. Climate*, 12, 3105-3120.

Kleeman, R., R. A. Colman, N. R. Smith and S.B. Power, 1996: A recent change in the mean state of the Pacific basin climate: observational evidence and atmospheric and oceanic responses. *J. Geophys. Res.*, 101, 20,483-20,499.

Latif, M., R. Kleeman, and C. Eckert, 1997: Greenhouse warming, decadal variability or El Nine? An attempt to understand the anomalous 1990s. *J. Climate*, 9, 2221-2239.

Liu, W.T., W. Tang, and R. Atlas, 1996: Responses of the tropical Pacific to wind forcing as observed by spaceborne sensors and simulated by model. *J. Geophys. Res.*, 101, 16,345-16,359.

Liu, W. T., W. Tang, and L.L. Fu, 1995: Recent warming event in the Pacific may be an El Nine. *Eos, Trans. Amer. Geophys. Union*, **76**, *429 & 43'7.*

Pacanowski, R. C., and G. Philander, 1981: Parameterization of vertical mixing in numerical models of the tropical ocean. *J. Phys. Oceanogr.*, 11, 1442-1451.

Smagorinsky, J., 1963: General circulation experiments with the primitive equations: I. The basic experiment. *Mon. Wea. Rev.*, 91, 99-164.

Trenberth and Hoar, 1996: The 1990-1995 El Nino-Southern Oscillation event: longest on record. *Geophys. Res. Lett., 23, 57-60.*

Wang, B., 199.5: Interdecadal changes in El Nino onset in the last four decades. *J. Climate, 8,* 267-285.